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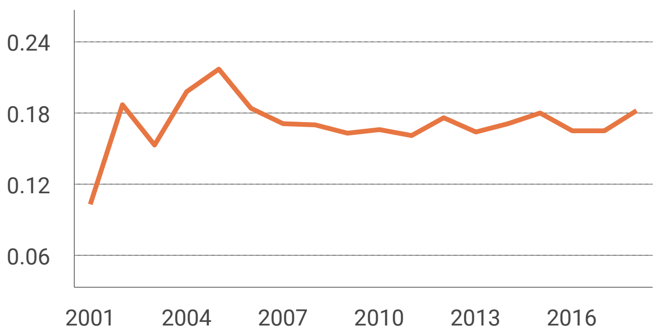

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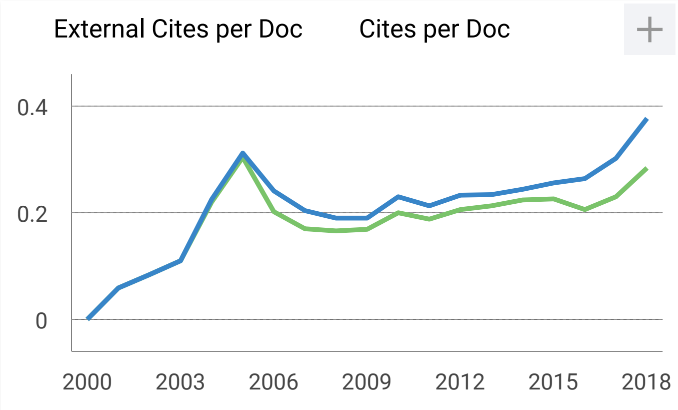

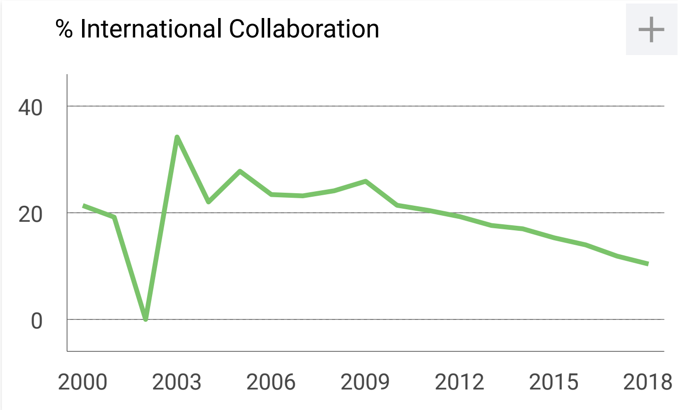

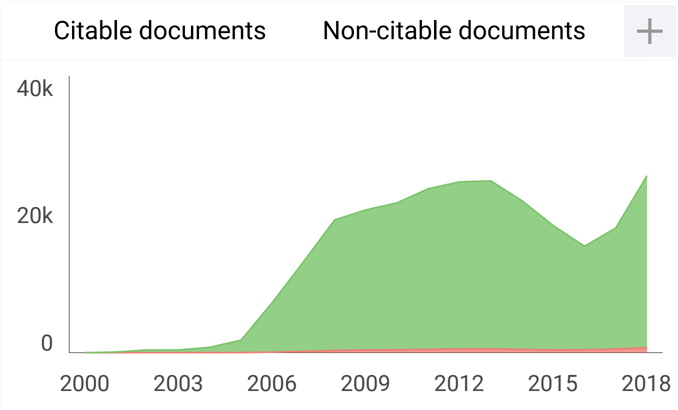

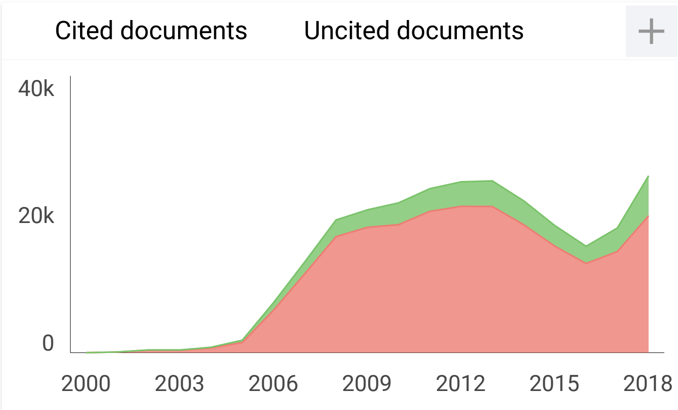

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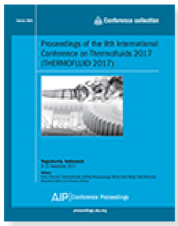

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Optimization of Wire Drawing Die's Cooling System

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Abstract. Wire drawing die wear is measured by the dilatation of die gap diameter. Many factors that contribute to wire drawing die wear, one of them is temperature of the wire during drawing process. Therefore, die cooling system have to be considered to reduce die wear. Water that is cooled by cooling tower is usually used as die coolant. If the heat is not transferred well to the coolant, then the die wear will happen faster and the die needs replacement more often. ASM International gives suggestion to maintain the die gap or the wire's temperature at 137°C during drawing process. At this temperature, die wear will be 0.01 mm for 500 km of drawing wire that contains 0.08 % Carbon. In a wire company that produces AISI 1010, wire was drawn from diameter 5.5 mm to 4.75 mm and die wear was 0.05 mm for 332.1 km of drawing wire. This die wear showed the existing die cooling system was not enough. Assessment of existing cooling system and numerical simulation were conducted to find solution. From the assessment, the cooling tower's average effectiveness was only 25.9%. Numerical simulation using Gambit, ANSYS Workbench, and ANSYS Fluent was conducted to obtain die gap surface temperature and some improvement of the cooling system. The mesh used in simulation is 0.7 mm interval and Standard K-Epsilon (SKE) is chosen as the viscous model. From the simulation, die gap or wire temperature was found 159.3°C. This value is much higher than 137°C that is recommended by ASM International. Some improvement proposed to the existing cooling system are: 1) Replacing the cooling tower or using water chiller to produce water flowing into die box at rate of at least 0.332 l/s and maximum temperature of 25°C; 2) Changing the die box shape into cylindrical shape.

INTRODUCTION

In a process called wire drawing, wire is drawn through a conical die to reduce its diameter. The wire may passes several dies until the wire reaches target diameter [1]. According to Pathan & Harne, some factors that affect the life of the die in drawing process are drawing force, lubricant used, coolant used, preprocessing of wire rod, semi angle of die, and die geometry [2], [3]. According to Gifford, a single drawing system can be used to reduce the cross-sectional area of the wire up to 45% [3]. When diameter reduction is large, the drawing force becomes larger, too [4]. The large force will produce higher heat generation [5]. Vega, et al. investigated the drawing force and the temperature values corresponding to different wire-drawing process speeds varying between 1 and 7 m/s. The experimental results show that the drawing force and the temperature depend on interface conditions as well as the wire materials [6]. Moon & Kim stated that though the wire is drawn in room temperature or cold wire-drawing process, heat is generated from plastic work and friction between wire drawn and the die. The increased temperature affects thermal expansion, deformation pattern [7]. They propose inverse engineering procedures to determine friction and thermal conditions. Deformation behavior of the wire and its temperature distribution in the die was simulated numerically [7]. Heat generation resulted in wire-drawing process, especially the high speed process to meet the demand is resulted from the plastic deformation and friction between the wires and die. This mechanical energy converts to heat and results in temperature rises that greatly affects lubricant, dies, and the final product properties [8]. However, the cooling with lubricant is not enough. It is because of the low surface area of the die. For this reason, some drawing die are water-cooled [3].

The wire die encounters wear because of the process. Pathan & Harne studied the wear of the die that is resulted by factor semi die angle, die geometry and hardness [2]. The wire die wear is characterized by the dilatation of the die

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gap. This dilatation will increase the wire diameter and reduce the product quality to an unacceptable level. One factor causes die wear is heating due to the friction, and if the frictional heating become excessive, it will accelerate the die wear [4], [9]. This excessive heating can be prevented by designing a proper cooling system for the process.

Figure 1 shows the relation between wire temperature in die gap and die wear rate based on experiment by Davis [9]. The die wear rate is defined by how much the die gap increases (in mm) per 500 km of wire pulling. Figure 1 also shows that the carbon composition in steel wire can affect the die wear rate, where each steel type have their optimum temperature to reduce the die wear rate.

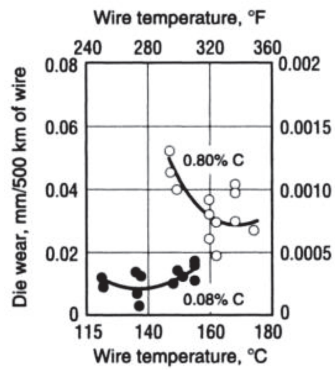


FIGURE 1. The relation between the wire temperature in die gap and die wear rate [9]

Based on site observation, it was found that in six working days the wire die used in Unit 1 of “XYZ” Company for drawing wire is worn to 0.05 mm, which is the limit tolerance of the die wear. The die was used to draw 23,713 kg or 332.1 km wire of SAE-AISI 1010 that contains 0.08 – 0.1% Carbon. Figure 1 shows that the die wear will be the least, i.e. 0.01 mm for pulling 500 km of wire when the wire temperature could be kept around 137°C. The die wear used in this company is 0.05 for 332.1 km of wire. This rate is much higher than it should be.

During observation, it was found that the water used as the cooling media of the die was not handled well. The cooling tower was not maintained well. The average temperature of water flowing in and out of cooling tower was 34.5°C and 32.4°C, respectively. So, the average water temperature reduction was only 2.1°C. The outlet water temperature was very high compare to wet-bulb temperature of the ambient air, which was around 27°C.

The goal of this research is to help “XYZ” Company improve their cooling system for wire drawing process and thus reducing the wire die wear rate. Figure 1 from ASM (American Society for Metals) International will be the main reference to determine cooling condition for the wire drawing process. The study focused on SAE-AISI 1010 wire drawing from diameter 5.5 mm to 4.75 mm.

PERFORMANCE OF EXISTING COOLING SYSTEM

The first step was observation to existing water cooling system of the die. “XYZ” Company is using cooling tower as their heat transfer machine. Figure 2 shows simple schematic of the measurement position and cooling tower position. Parameters taken to assess the cooling tower performance are:

- RPM of pump that sending water to cooling tower.
- The temperature of water at inlet and exit of cooling tower. The temperature of water entering cooling tower could be assume the same of water in supplying pond.
- The temperature of air entering and leaving cooling tower.
- The air velocity at exit of cooling tower.
- The wet bulb temperature of ambient air.
- The temperature of water in reservoir pond which holds water from the cooling tower before entering the wire plant.

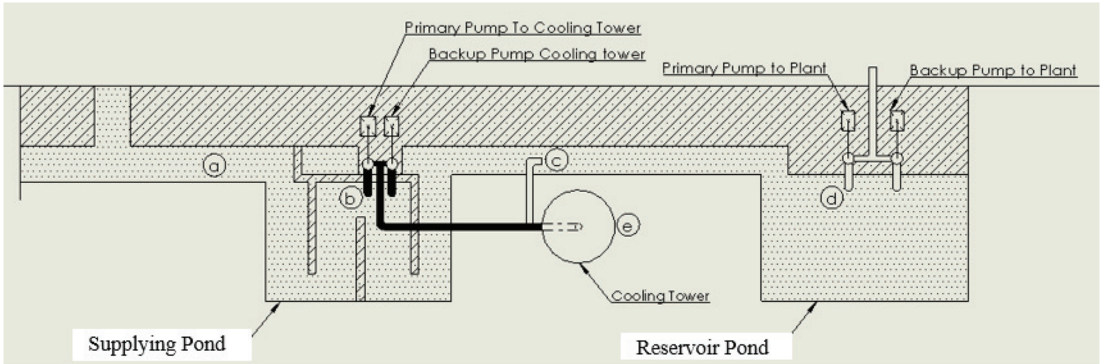


FIGURE 2. Layout of cooling tower, supplying pond (which holds water before entering cooling tower) and reservoir pond (which holds water before entering Plant).

The performance of cooling tower is cooling range, approach, and its effectiveness, ε. The cooling range is the temperature difference between the water inlet and water exit. Approach is the difference between the cooled water and the ambient air wet bulb temperatures. The effectiveness is defined as how much the cooling tower can actually reject heat (Cooling Range) compared to the how much the cooling tower can reject heat until the water reach ambient wet bulb temperature (Cooling Range + Approach), as written in Equation (1) [10]. The result of cooling system using cooling tower is shown in Table 1.

$$\varepsilon = \frac{\text{Cooling tower range}}{\text{Cooling tower range} + \text{Cooling tower approach}} \times 100\% \tag{1}$$

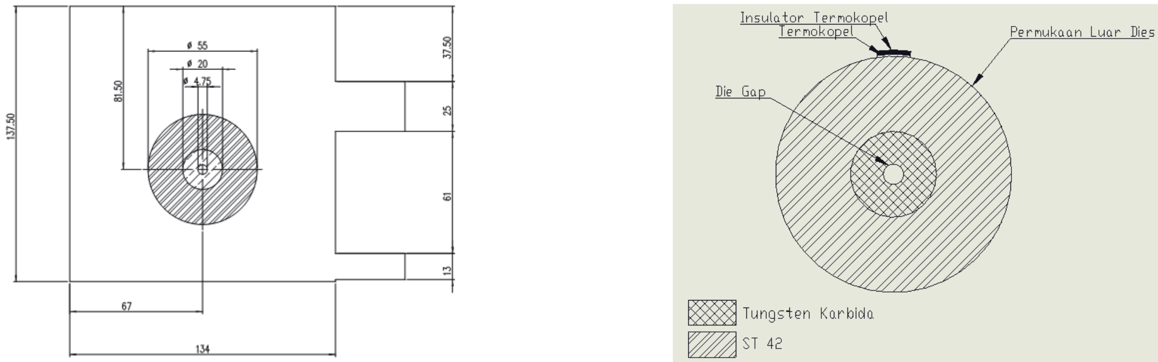
TABLE 1. Measurement results for the existing cooling tower's parameters

RPM	$T_{air, in}$ (°C)	$T_{air, out}$ (°C)	V_{air} (m/s)	$T_{water, in}$ (°C)	$T_{plant, out}$ (°C)	$T_{water, out}$ (°C)	$T_{resvr\ pond}$ (°C)	Range (°C)	Approach (°C)	ε (%)
800	32.5	32.9	6.7	32.8	33.4	31.3	31.1	1.5	4.3	25.9
850	33.4	33.8	6.8	34.6	35	32.2	31.9	2.4	5.2	31.6
900	33.8	34.2	6.8	34.7	34.8	32.1	32	2.6	5.1	33.8
950	34.1	34.5	6.7	35.8	36	33.8	33.2	2	6.8	22.7

The effectiveness of cooling tower in Table 1 is rather low. From observation, it was found that the cooling tower was placed very close to the wall. When it is placed too close to wall, then its cooling capacity will be much lower [10]. This is because the cooling process of water depends on ambient air that is drawn into tower naturally or mechanically. In this case, the air is drawn mechanically using a fan installed on the top of the cooling tower. When the tower is too close to wall, then the air flowing out of tower is recirculated drawn back into tower. Thus, the entering air wet bulb temperature is higher and water can not be cooled optimally.

Besides investigating the cooling tower, it is also necessary to study the die itself. Figure 3a) shows the die and die box geometry in 2D and Fig. 3b) shows the installation of thermocouple and die material. To assess the cooling system in the die, some measurement conducted were: temperature of die's surface, temperature and flow rate of the water flowing in and out of the die. Some thermocouples type K were used. The water flow rate entering die was 0.125 l/s and inlet diameter of the die box was 13 mm. Water temperature entering and leaving die box were 35°C and 36°C, respectively. While the temperature of die's surface was 65.9°C or 338.9K at steady condition. The temperature at die gap or the wire temperature during drawing process must be higher than this number. Unfortunately, it is not possible to measure the temperature on die gap. So, a numerical simulation was used to investigate the temperature of wire drawing process and be compared to the graph in Fig. 1.

The water entering die box was quite high compared to ambient wet air temperature. It was a sign that the cooling tower was not performing well. Since the existing cooling tower did not perform well, then some options to improve existing cooling system were proposed. The options are: increasing the water inlet volume flow rate with the same water inlet temperature; lowering the water inlet temperature at the same water inlet flow rate; combination of increasing water flow rate and lowering its inlet temperature. A numerical simulation was conducted to study these options.



a) Die and die box geometry b) die material and installation of thermocouple

FIGURE 3. Scheme of wire drawing die used

The water temperature difference as it flew through die box was small. It showed that the heat transfer from the die during wire drawing process to the water was not good. The numerical simulation is to study if the die box geometry could be improved. The simulation was conducted to change the shape of die box from box shape to cylindrical.

NUMERICAL SIMULATION

Numerical simulation was done using three software, which is GAMBIT, ANSYS Workbench, and ANSYS Fluent. GAMBIT software was used to create 2D geometry of die box and die and also was used to create mesh needed and boundary conditions. ANSYS Workbench software was used to find out the value of average stress that wire experienced when it passed die gap during drawing process. This average stress value can be used to find out how much drawing force the wire encounters in die gap, as writtten in Equation (2) [4].

$$F = \sigma_o A_f \left[\left(1 + \frac{\mu}{\alpha}\right) ln \left(\frac{A_0}{A_f}\right) + \frac{2}{3}\alpha \right] \tag{2}$$

Where σ_o is the average stress that the wire experienced in the die gap. A_f and A_o are the cross-section area of the wire that entering the die and exiting the die respectively, μ is the friction coefficient between the wire and the die and α is die angle in radian. The force that have been experienced by the wire in die gap (F) can be used to find how much the heat that being exerted due to friction with Equation (3) [5].

$$q = \mu . F . V \tag{3}$$

The heat flux can be obtained by dividing the value of the exerted heat due to friction from Equation (3) with the contact area between the wire and die gap. The heat flux data combined with other data like measurement of die box geometry, volume mass flow rate and temperature of water that entering into die box and exiting from die box will become input for ANSYS Fluent to obtain die gap temperature.

Validation of the model and mesh design was conducted by comparing the result from numerical simulation with data collected in plant, i.e. the die surface temperature. The mesh should be checked to confirm that it meets the independency test. Then, the viscous model should also be checked to confirm that the simulation gives the correct results. Since the geometry is not too complicated, then the common viscous model shall be used. The simulation will be conducted with *Standard K-Epsilon* (SK-ε), *RNG K-Epsilon* (RNGK-ε), *Realizable K-Epsilon* (RK-ε), *Standard K-Omega* (SK-ω), and *SST K-Omega* (SSTK- ω). Then, the result of simulation will be compared with data collected to choose the right viscous model. The optimization process will be conducted after the model used in numerical simulation was proved valid.

The wire was drawn from diameter 5.5 mm to 4.75 mm with velocity 2.9 m/s while it passed through the die. Figure 3 shows the die and die box geometry in 2D. The inlet water volume flow rate was measured to be 0.125 l/s through pipe which diameter was 13 mm. The water inlet velocity was 0.942 m/s. From measurement, it was found that the inlet water temperature was 35ºC and the die surface temperature was 65.9ºC. This inlet water velocity and temperature will later be used to define the die box boundary condition in ANSYS Fluent simulation, and the measured die outer surface temperature will be used to validate the simulation. Before simulating the die gap temperature with ANSYS Fluent, it is necessary to get the heat flux in die gap as the result of drawing wire. This heat flux was obtained from Equation (3) that used Equation (2) and result from ANSYS Workbench simulation.

ANSYS Workbench Simulation

The ANSYS Workbench simulation process was started by knowing some of important data such as friction coefficient between die gap surface-made from tungsten carbide-with steel wire with powder lubricant on its surface, which is 0.12 [11]. The wire pulling drum has angular velocity of 94.2 RPM and the drum's diameter is 58.6 cm, then the drum tangential velocity is 2.9 m/s, which is the same with wire velocity. The detail of support placement and velocity vector is shown in Fig. 4, the detail of the wire and die mesh is shown in Fig. 5. The wire will experience stress in die gap with minimum value of 38.37 MPa to maximum value of 53.15 MPa, or 45.76 MPa in average, as shown in Fig. 6 and 7.

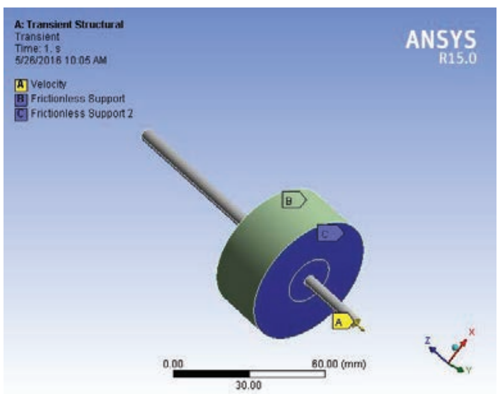


FIGURE 4. Constraint setup for die and wire

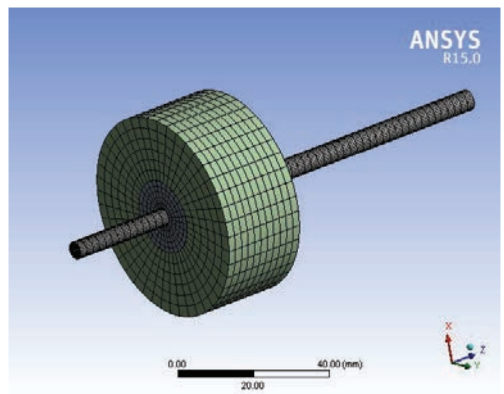


FIGURE 5. Mesh detail for wire and die

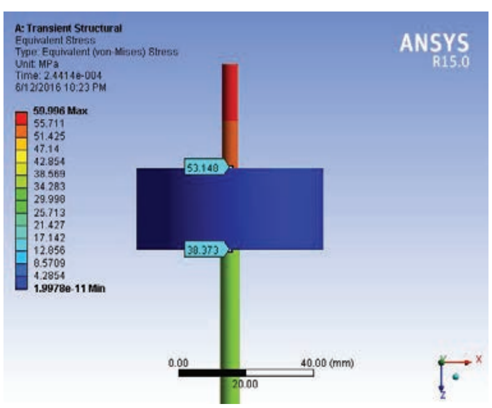


FIGURE 6. Simulation result for wire drawing process

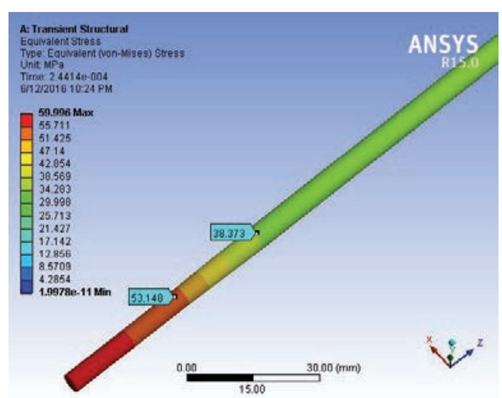


FIGURE 7. Detail of simulation result for the wire

The die's approach angle (α) is 6.5º and using Equation (2), the frictional force between wire and die gap surface is 548.3 N. Substitute this friction force to Equation (3), it was found that the heat released during the drawing process was 191 Watt. Dividing this value with the die gap surface area which is 2.25 x 10^{-4} m^2 (from die's specification) gives heat flux equals 848 kW/m^2. This heat flux will be given as boundary condition received by the die gap inner surface in numerical simulation using ANSYS Fluent.

ANSYS Fluent Simulation

It is necessary to find out what is the best mesh and viscous model that will give small error from the actual measurement. After designing the mesh using GAMBIT software, the next step was doing grid or mesh independency. So, the die box and die was meshed with various mesh, and simulated with Standard K-Epsilon viscous model. The mesh produced by GAMBIT is shown in Fig. 8. The mesh independency test result is shown in Table 2. From Table 2, it is shown that the size of the mesh gave small error, i.e. less than 5%. Thus, all of the designed mesh is already independent of the mesh size. Yet, the interval size of 0.7 mm gives the smallest error compare to the actual die surface temperature, which is 65.9^{o}C or 338.9 K. So, the simulation with ANSYS Fluent used this 0.7 mm interval mesh.

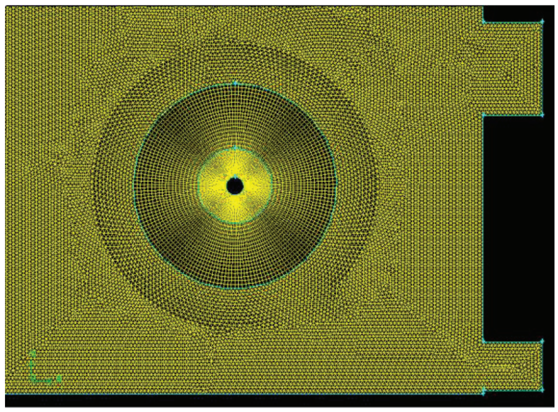


FIGURE 8. Mesh detail for die box and die created with GAMBIT software

TABLE 2. Mesh independency test results for various mesh interval

Mesh Interval	Worst Quality	Simulated die surface's temperature (K)	Error
0.5	0.51	332.9	1.8 %
0.7	0.51	340.3	0.4 %
1	0.47	346.3	2.2 %
3	0.53	349.8	3.2 %
7	0.77	350.2	3.3 %

The next step is to test some of the viscous model to find the suitable viscous model. Table 3 shows the result of simulation with some viscous model. Actually, all viscous model gives error less than 5%. Yet, Standard K-Epsilon (SKE) viscous model gives the smallest error between simulated die outer surface temperature compare to actual temperature. So, for the next numerical simulation, SKE was used as the viscous model.

TABLE 3. Simulation results for some viscous model

Viscous Model	Simulated die surface's temperature (K)	Error (%)	Inner die Temperature (K)
SKE	340.3	0.4	432.3
RNG-KE	341.8	0.9	433.2
RKE	342.5	1.1	435.9
SKW	327.1	3.5	414.2
SSTKW	329.9	2.7	417.7

From this simulation, the wire temperature or the die gap was known as shown in Table 3. It reached 432.3 K or 159.3^{o}C. This value is higher than the recommended value from ASM International which is 137^{o}C. It might be the reason that die needs replacement more often. The die wear could be only 0.01 mm for 500 km wire drawn as shown in Fig. 1. Yet, the die wear in this manufacturer was 0.05 mm for 332.1 km of wire drawn. It is appropriate to conclude that the current die cooling system is not enough.

Another important results from the simulation are the temperature or velocity contour, as shown in Fig. 9 and 10. The velocity contour in Fig. 10 gives information of the velocity distribution of the cooling water outside the die in the die box. It shows that the velocity of water flowing around the die especially on top is very low. It means only little water flowing near and thus cooling the die. Only small portion of heat flux generated by the drawing wire process is transferred to the cooling water. This causes the water temperature in Fig. 9 looks low and the die temperature is high, especially the inner surface of die that could reach 432.3 K or 159.3^{o}C.

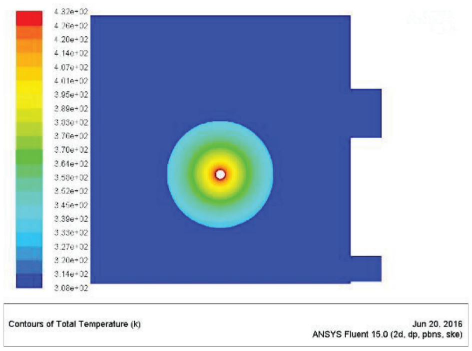


FIGURE 9. Contour image of temperature for die and die box

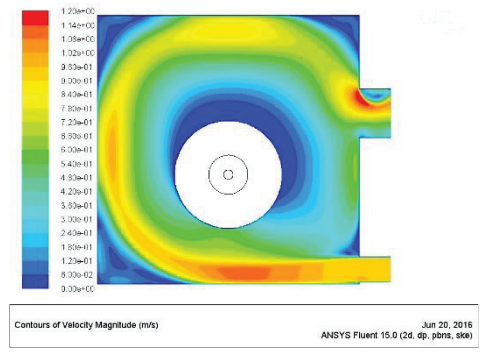


FIGURE 10. Contour image of velocity for die and die box

RESULTS AND DISCUSSION

From simulation with ANSYS Fluent, it was found that when the water inlet flow rate was increased but its inlet temperature maintained constant at 308K, the die gap temperature profile was shown in Fig. 11. When the water inlet flow rate was maintained constant at 0.125 l/s, but its inlet temperature was lowered, the die gap temperature was shown in Fig. 12. The combination of both was shown in Fig. 13.

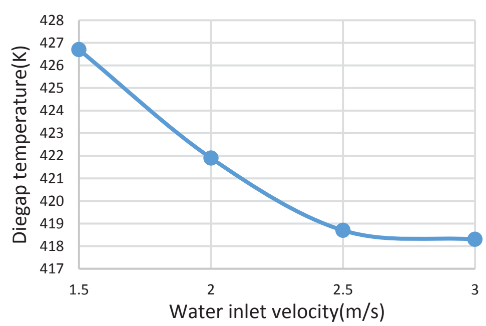


FIGURE 11. The die gap temperature as function of flow rate from simulation

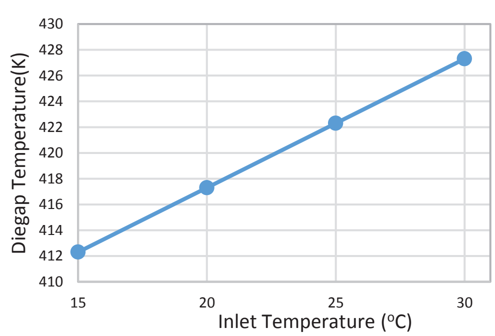


FIGURE 12. The die gap temperature as function of water inlet temperature from simulation

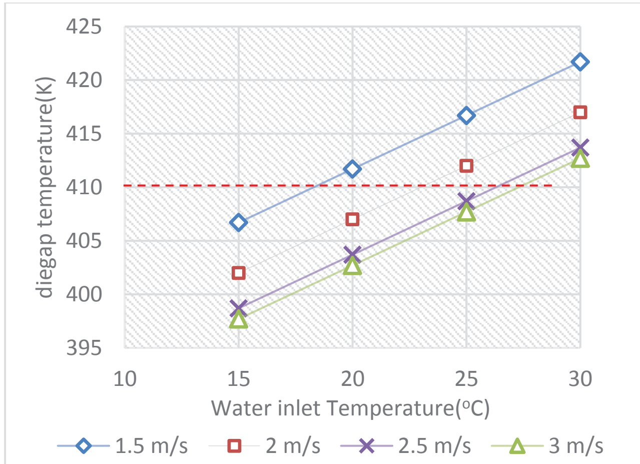


FIGURE 13. The die gap temperature as function of water inlet temperature and flow rate from simulation

The dashed line was drawn at 410 K (137°C) as the recommended die gap temperature by ASM. Improvement of the cooling system should make the die gap temperature equals to or lower than 410 K. Figure 11 shows that when the water was entering die box at the existing temperature, i.e. 308 K (35°C), the die gap temperature will always be more than 410 K. Thus, the inlet water temperature shall be lowered than the existing. Figure 12 shows that for the existing inlet water flow rate, 0.125 l/s, the water should enter die box at temperature lower than 15°C. This number is less than the air wet bulb temperature. Thus, it means the company needs a chiller to produce chilled water. Figure 13 shows that the cooling water can be entering at 25°C with higher velocity (2.5 m/s) or flow rate (0.332 l/s).

The other simulation is to study if the die box geometry could be improved. The shape of die box was changed from box to cylindrical. The cooling water is supposed to distribute better and contact with all surface of the die gap in a cylindrical die box. Doing so will improve the convective heat transfer from the surface of the die to the water flowing around the die. Simulation was conducted with the value of existing water temperature and flow rate entering the die box, i.e. 308 K and 0.125 L/s. The result of this simulation is shown in Fig. 14. The contour of cooling water temperature as it flows to the cylindrical die box is very different than the box shape. The water absorbs the heat flux from the wire drawing process and reduces the temperature in the die gap to 136.6°C. This is lower than the existing die gap temperature with box shape (159.3°C) and meet the ASM's recommendation (137°C).

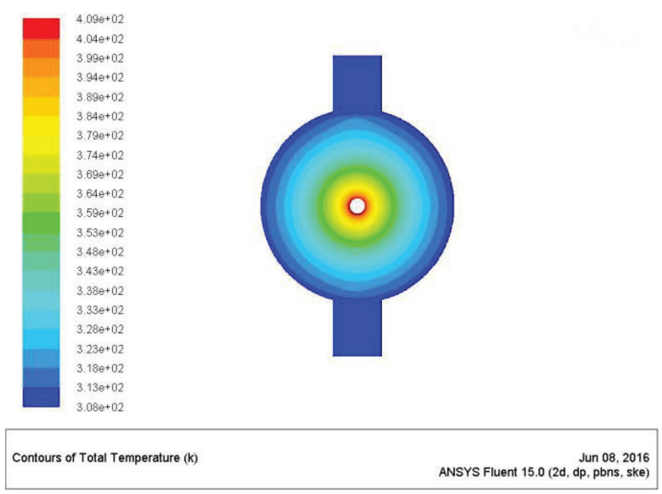


FIGURE 14. Contour image of temperature for cylindrical die box

CONCLUSION

The wire drawing process generates heat as a result of reducing the cross-section of a wire in the wire itself and the die. The heat shall be transfered to the cooling water flowing outside die in the die box. If the heat is not transferred well, then the die wear will happen faster and the die needs replacement more often. ASM International gives suggestion to maintain the die gap or wire temperature at 137ºC during pulling process. At this temperature, die wear will be 0.01 mm for 500 km of drawing wire that contains 0.08 % Carbon.

In a wire company that produces AISI 1010, wire was drawn from diameter 5.5 mm to 4.75 mm and die wear was 0.05 mm for 332.1 km of drawing wire. This die wear showed the existing die cooling system was not enough. Assessment of existing cooling system and numerical simulation were conducted to find solution.

From the assessment, the cooling tower's average effectiveness was only 25.9%. Numerical simulation using Gambit, ANSYS Workbench, and ANSYS Fluent was conducted to obtain die gap surface temperature and some improvement of the cooling system. The mesh used in simulation is 0.7 mm interval and Standard K-Epsilon (SKE) is chosen as the viscous model. From the simulation, die gap or wire temperature is found 159.3ºC. This value is much higher than 137ºC that is recommended by ASM International.

Some improvement proposed to the existing cooling system are:

1. Replacing the cooling tower or using water chiller to produce water flowing into die box at rate of at least 0.332 l/s and maximum temperature of 25ºC.
2. Changing the die box shape into cylindrical shape.

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REFERENCES

[1] S. Semiatin, ASM Handbook Volume 14: Forming and Forging., ASM International., 1988.

[2] Z. Pathan and M. Harne, "A Review on Wear Analysis of Wire Drawing Die," *International Advanced Research Journal in Science, Engineering and Technology Vol 3, Special Issue 1,* pp. 268-272, 2016.

[3] R. B. Gifford, An investigation of product quality modification capabilities during wire drawing, Lehigh University, 2000.

[4] S. Kalpakjian and S. Schmid, Manufacturing, Engineering and Technology 6th edition, Prentice Hall, 2009.

[5] B. Bhushan, Introduction to Tribology: Second Edition, New York: John Wiley & Sons, Inc, 2013, p. 279.

[6] G. Vega, A. Haddi and A. Imad, "Temperature effects on wire-drawing process: Experimental investigation," *International Journal of Material Forming,* 2009.

[7] C. Moon and N. Kim, "Analysis of wire-drawing process with friction and thermal conditions obtained by inverse engineering," *Journal of Mechanical Science and Technology 26 (9),* p. 2903~2911, 2012.

[8] A. El-Domiaty and S. Z. Kassab, "Temperature rise in wire-drawing," *Journal of Materials Processing Technology 83,* p. 72–83, 1998.

[9] R. J. Davis, ASM Specialty Handbook: Tool Materials., New York: ASM International., 1995.

[10] H. W. Stanford, HVAC Water Chillers and Cooling Towers: Fundamental, Application and Operation, CRC Press, 2012.

[11] S. M. Byon, J. S. Lee, D. W. Lee, Y. H. Lee and Y. Lee, "Effect of Coating Material and Lubricant on Forming Force and Surface Defects In Wire Drawing Process," 104-110., 2011.